Evolution of the RHIC Machine Capability

RHIC performance

Luminosity upgrade using
full energy electron cooling (RHIC II)

Electron Beam Ion Source (EBIS)

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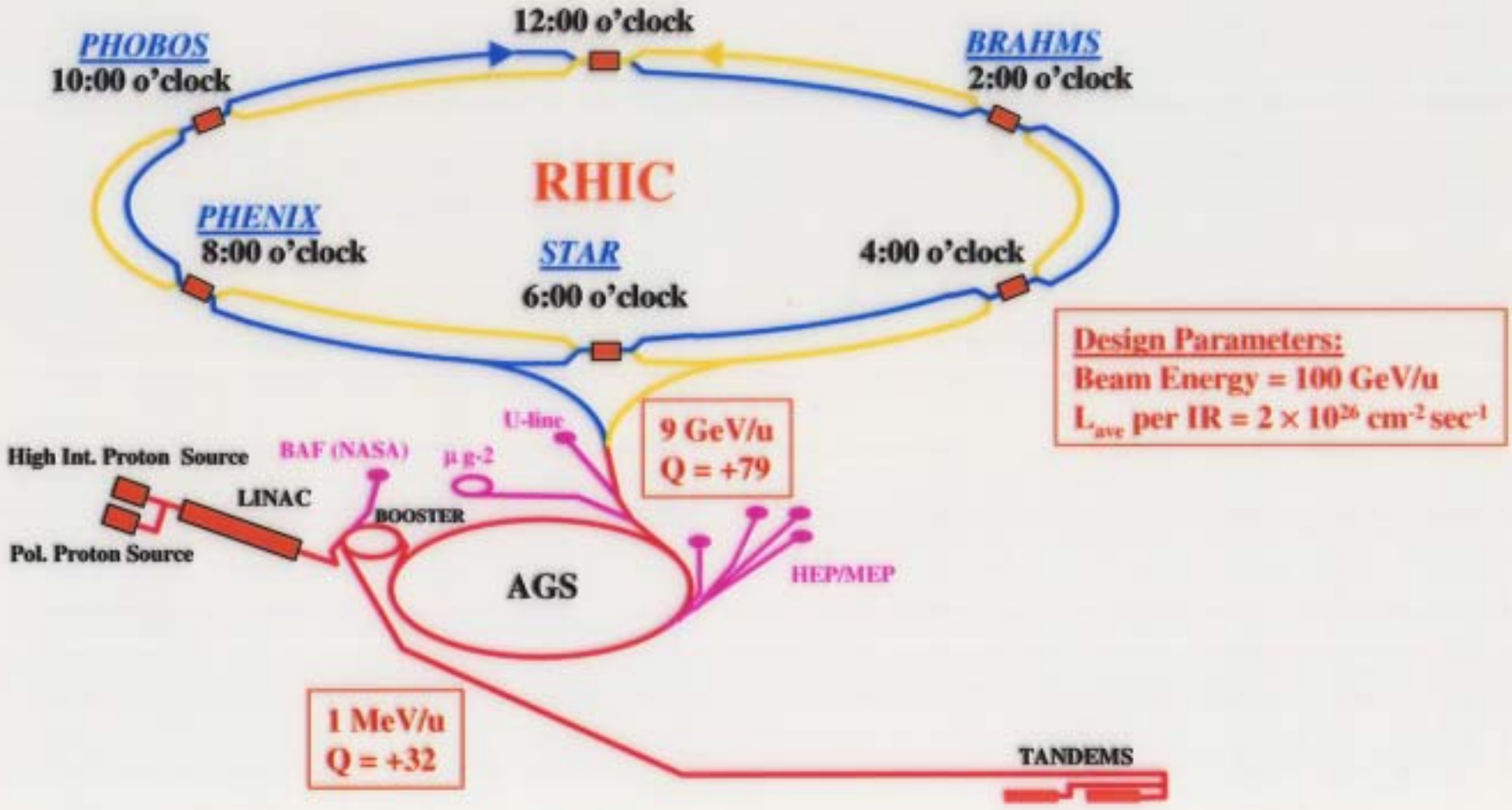
Thomas Roser
RHIC Detector Workshop
November 13 - 14, 2001

Gold Ion Collisions in RHIC



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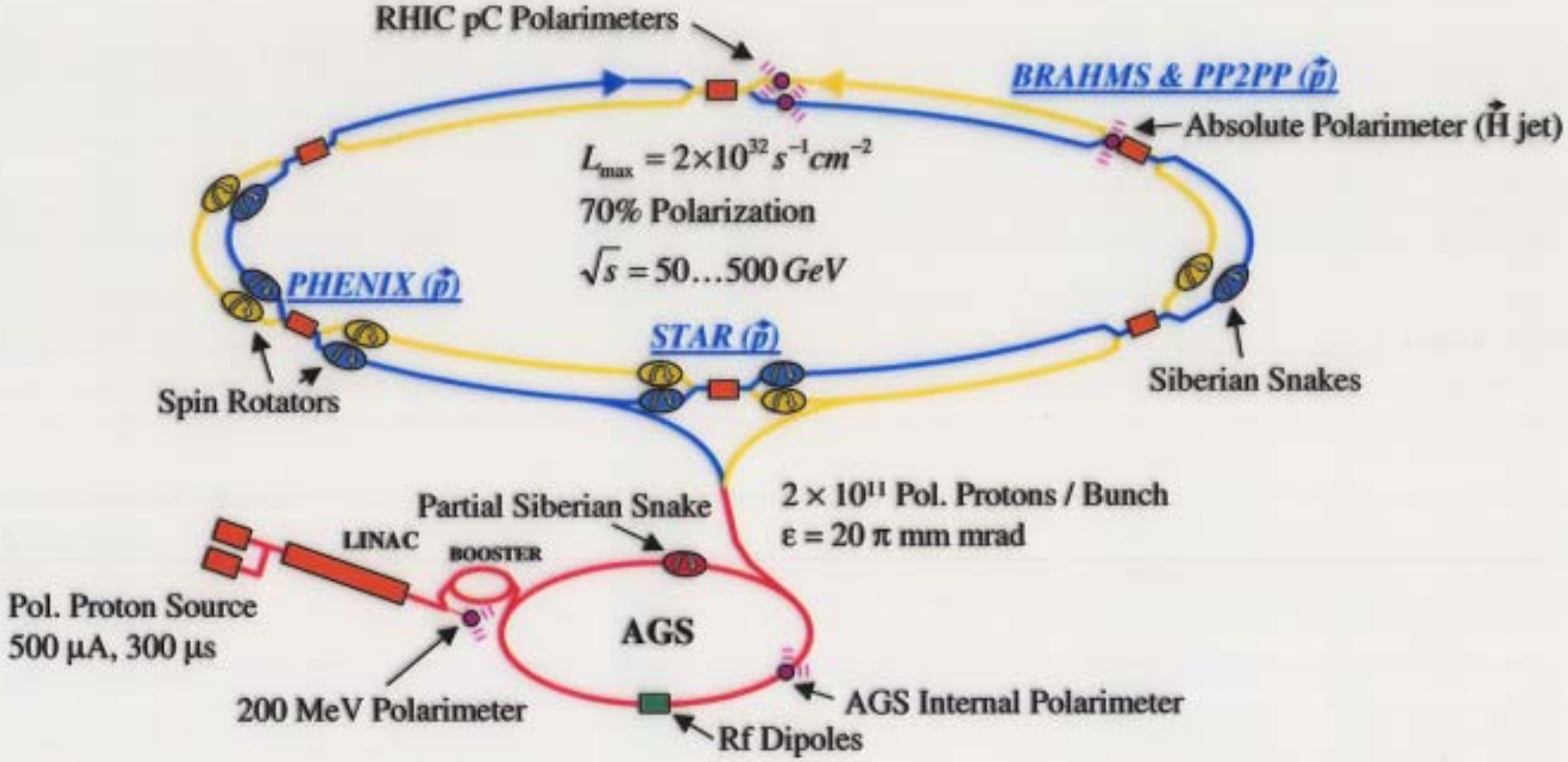
Polarized Proton Collisions in RHIC



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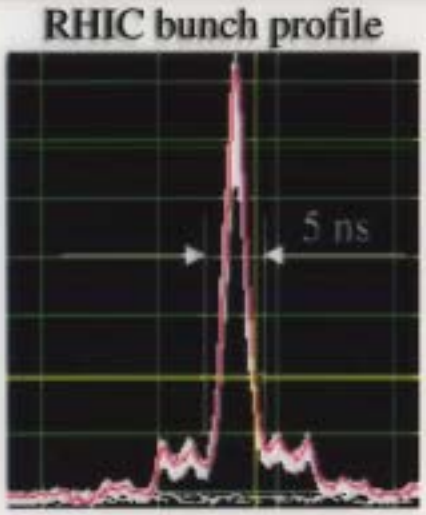
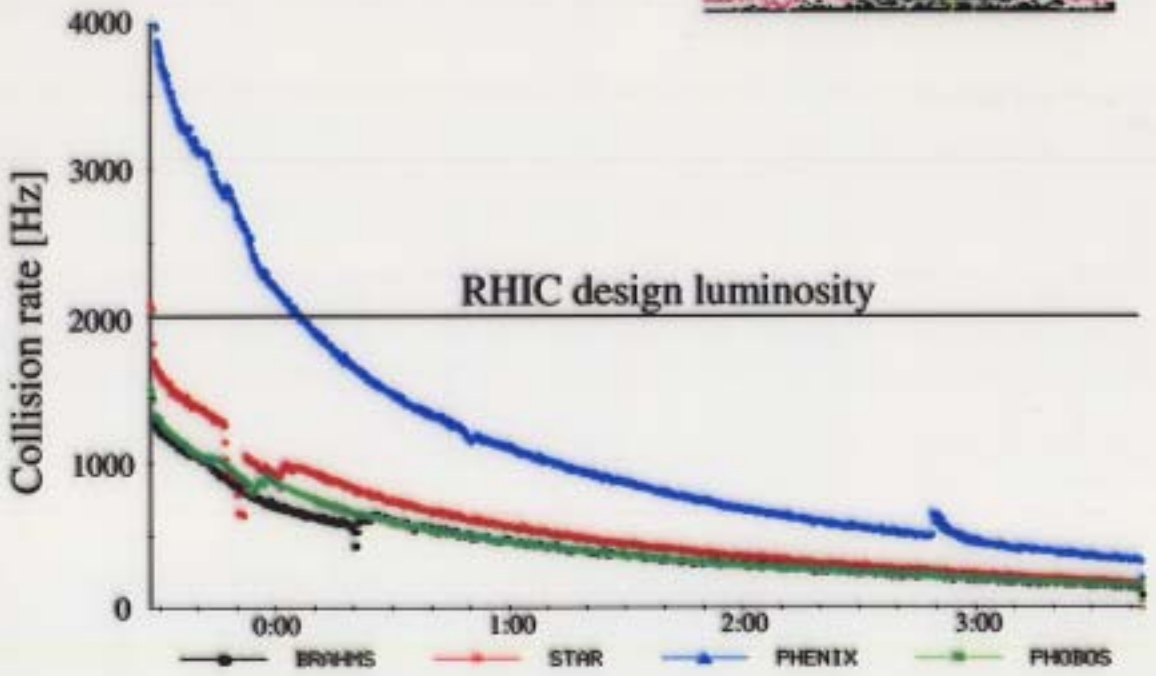
RHIC performance

- Collisions at RHIC design beam energy (100 GeV/nucl)
- 200 MHz rf system operational
  - 5 ns bunch length and an interaction region with $\sigma \sim 25$ cm
- Luminosity exceeding RHIC design luminosity of 2×10^{26} cm^{-2} s^{-1}
- 40% availability is limiting total integrated luminosity





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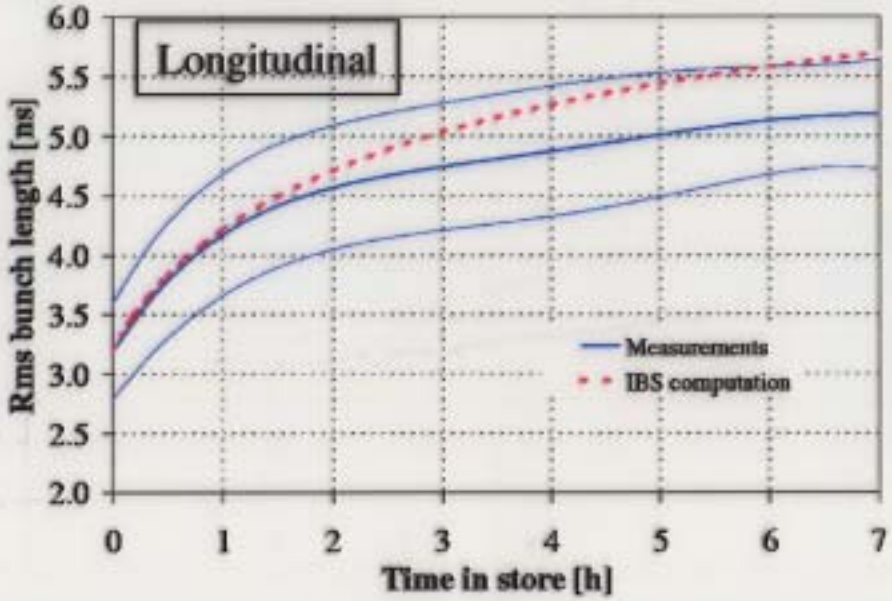
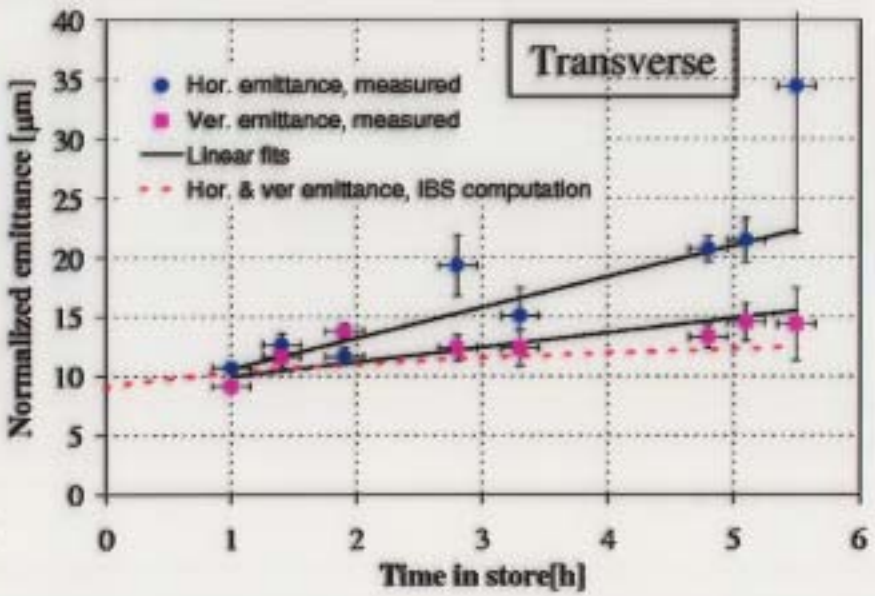
Intra-Beam Scattering (IBS) in RHIC





- Longitudinal emittance growth agrees well with model
- Additional source of transverse emittance growth
- IBS determines RHIC Au performance
- Eventually will need electron cooling (see below)

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RHIC upgrade opportunities

Possible upgrades for heavy ions:

- Increase luminosity
- Increase atomic number: $Au^{197} \rightarrow U^{238}$ (EBIS)
- Increase c.m. energy: 200 GeV $\rightarrow$ 240 GeV

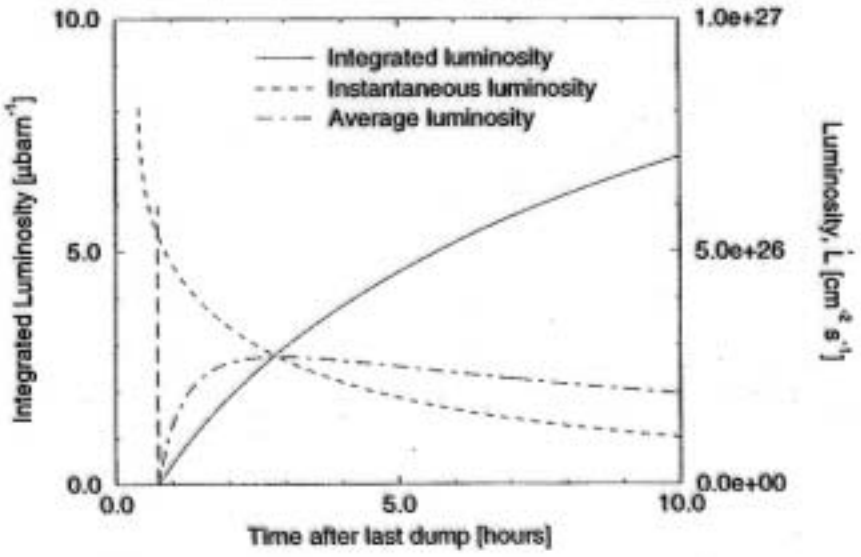
Possible upgrades for protons:

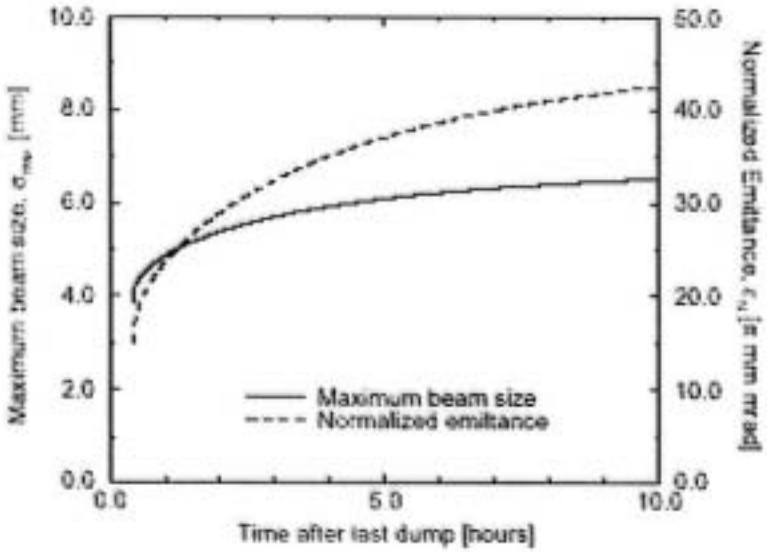
- Increase luminosity
- Increase c.m. energy: 500 GeV $\rightarrow$ 600 GeV
- Further luminosity upgrade

RHIC design luminosity

$$L = \frac{3 f_{rev} \gamma}{2} \frac{N_b N^2}{\varepsilon \beta^*} = 9 \text{ to } 1 \times 10^{26} \text{cm}^{-2}\text{s}^{-1} \text{ over } 10 \text{ hours}$$

$$N_b = 56\,;\; N = 1 \times 10^9\,;\; \varepsilon = 15 \text{ to } 40\pi\mu\text{m};\; \beta^* = 2\text{m}$$





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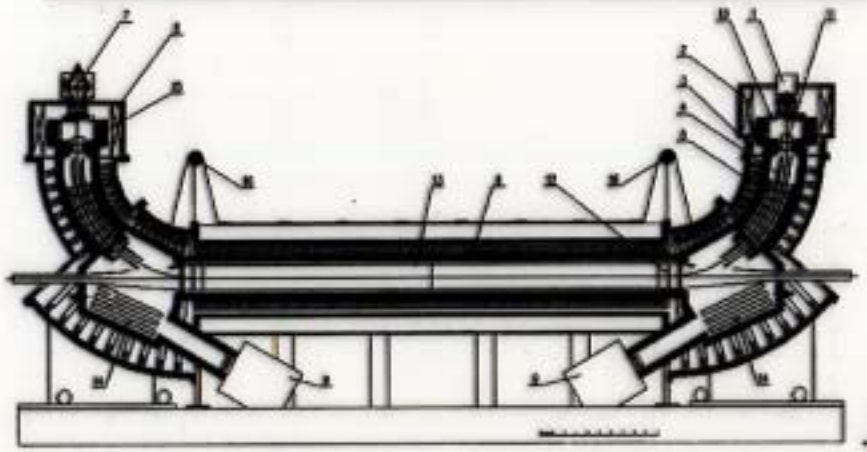
RHIC Upgrade Possibilities

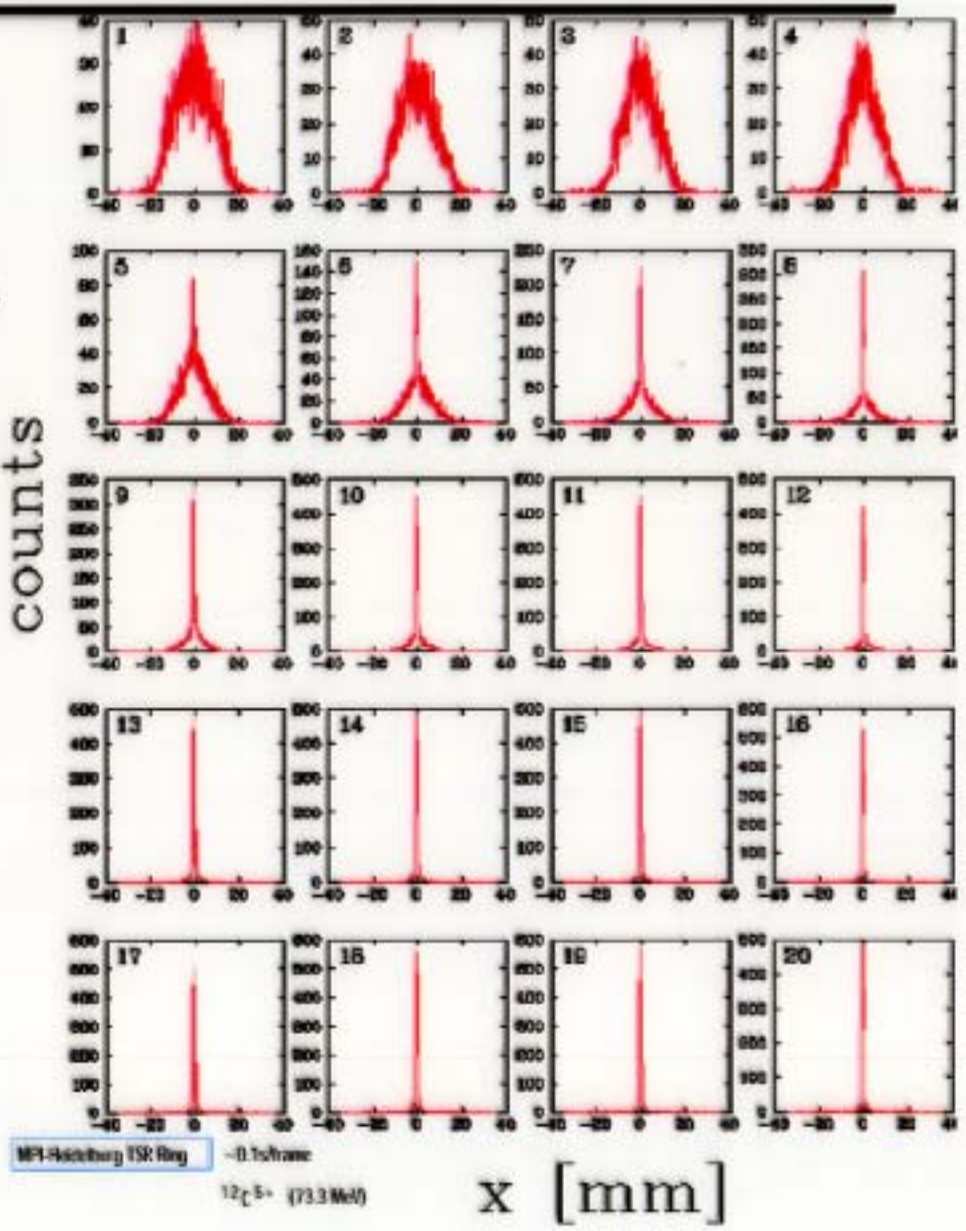
- 'Enhanced' luminosity (x4) possible with existing machine:
  - Double the number of bunches to 112
  - Decrease β^* from 2 m to 1m
- Further luminosity upgrades can be achieved by:
  - Decreasing β^* further with modified optics
  - Increasing bunch intensity
  - Decreasing beam emittance
- All options are limited by intra-beam scattering and require beam cooling at full energy!
- Preliminary study on RHIC electron cooling shows that luminosity can be increased ten times.
- Energy upgrade to 120 x 120 GeV/u (Au) or 300 x 300 GeV (protons) possible by replacing the DX magnets. (Present DX magnets have the smallest operational margin)

Electron Cooling at RHIC Storage Energy

- RHIC performance is limited by intra-beam scattering.
- Electron beam cooling at full RHIC energy could eliminate this limitation and even reduce beam emittance further.
- Feasibility supported by study produced by BINP (V. Parkhomchuk et al.)
- Bunched electron beam requirements for 100 GeV/u gold beams:
  $E = 54$ MeV, $\langle I \rangle \leq 100$ mA, electron beam power: ≤ 5 MW!
- Requires high brightness, high power, energy recovering superconducting linac, almost identical to IR FEL at TJNAF
- Has several applications at BNL: PERL, eRHIC (EIC)
- First linac based, bunched electron beam cooling system used at a collider
- First high p_t electron cooler to avoid recombination of e^- and Au^{79+}

Electron cooling of low energy beams





Transverse beam cooling at the Heidelberg Test Storage Ring (TSR)

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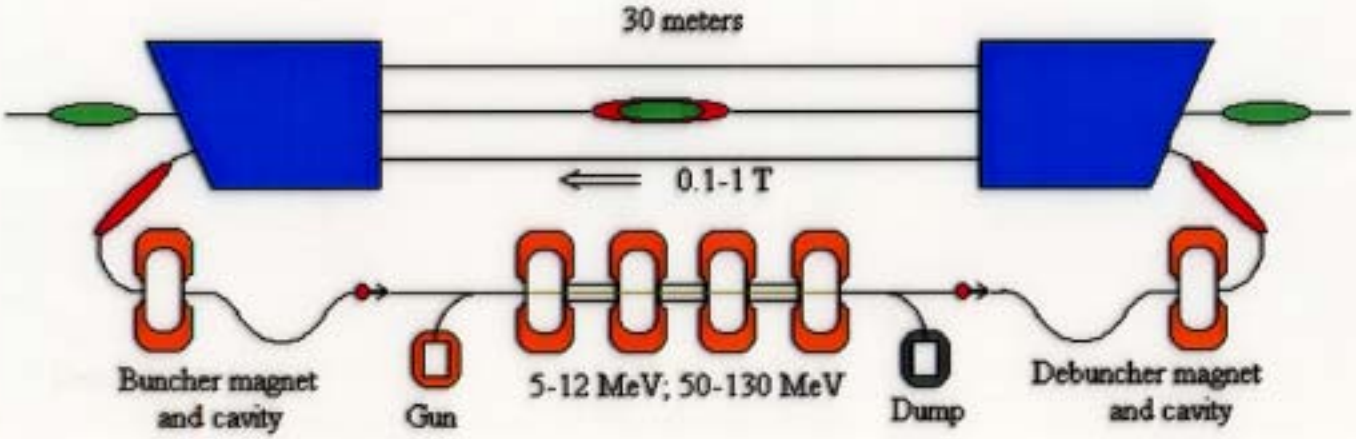
The RHIC Electron Beam Cooler



R&D issues:

High intensity photocathode electron gun

High efficiency energy recovering sc linac with magnetized electron beam

Efficient electron beam transport and debunching/bunching

High precision (10 ppm) solenoid for 30 m cooling section.

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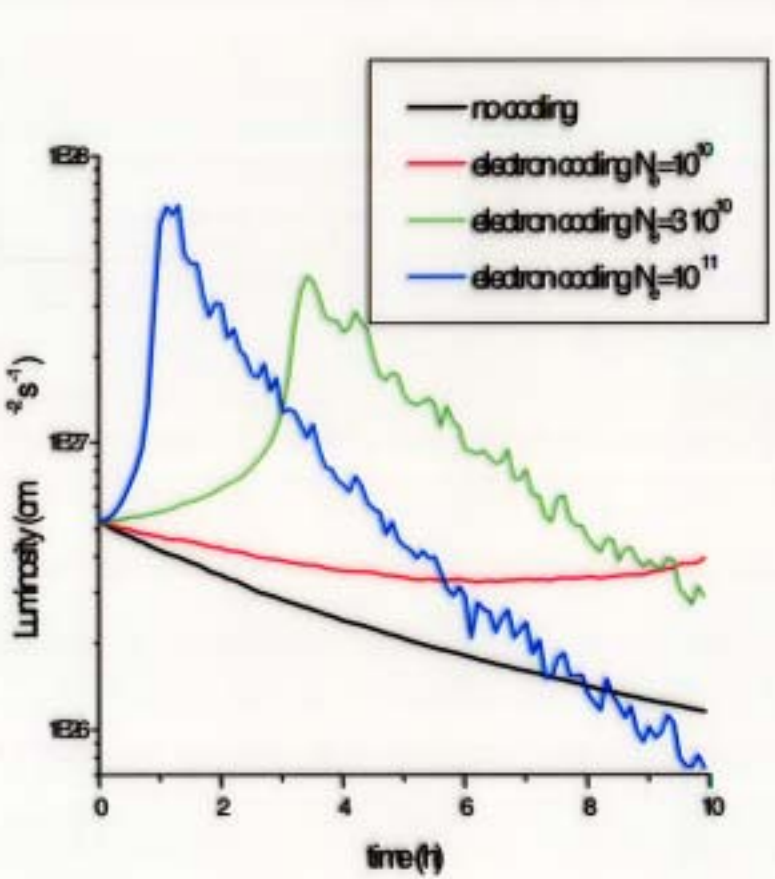
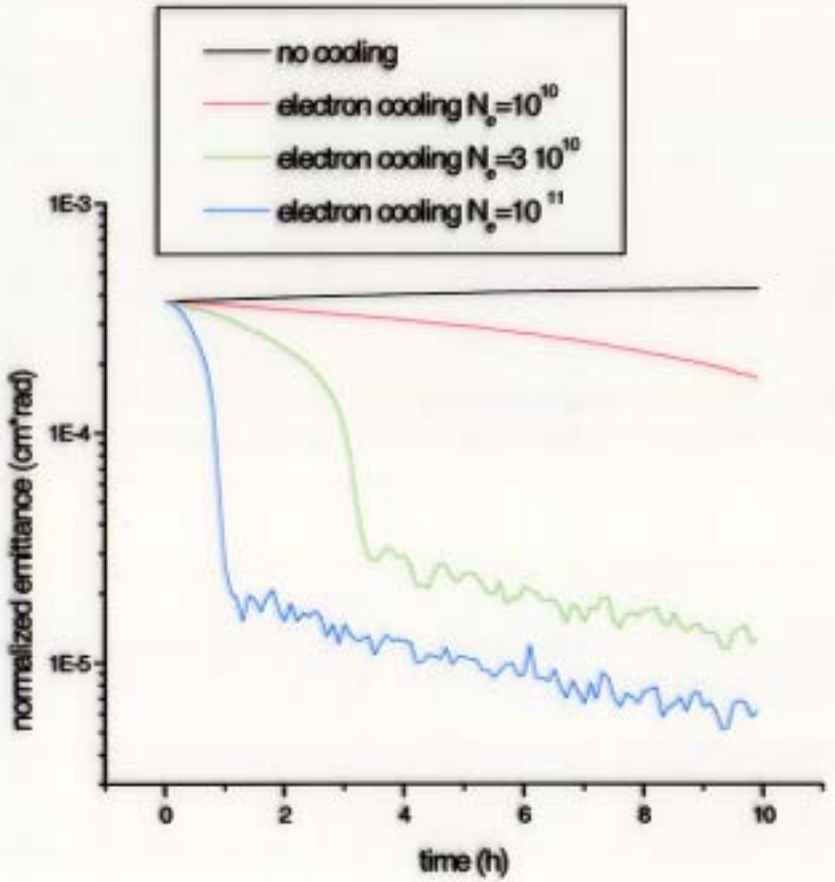
RHIC Luminosity and Emittance with Cooling





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RHIC beam cooling R&D

Feasibility report completed in April 2001, start design.

R&D items:

- High precision solenoid (10 ppm)
- High brightness photocathode electron gun
- A high-current, low-energy-spread linac

2003:[$2.0M]	Build high brightness cathode gun with required duty cycle
	Start construction of energy recovering SC linac
	Start construction of solenoid prototype
2004:[$2.0M]	Start beam tests with photocathode gun
	Complete solenoid prototype
2005:[$2.0M]	Complete and test energy recovering SC linac

Project: $60M (incl. $6M R&D), Construction: 2005 - 2008

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Heavy Ion Luminosity Upgrades

	RDM	RDM+	RHIC II
Initial emittance(95%) πμm	15	15	15
Final emittance (95%) πμm	40	40	3
Beta function at IR [m]	2.0	1.0	$1.0 \rightarrow 0.5$
Number of bunches	60	120	120
Bunch population [10^9]	2	2	2
Beam-beam parameter per IR	0.0016	0.0016	0.004
Angular size at IR [μrad]	108	153	95
RMS beam size at IR [μm]	216	150	95
Peak luminosity [10^{26} cm^{-2} s^{-1}]	8	32	83
Average luminosity [10^{26} cm^{-2} s^{-1}]	2	8	70

RDM and RDM+ assume 10 hr stores

RHIC II includes electron beam cooling and assumes 5 hr stores since burn-off is high

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Proton Luminosity Upgrades

	RHIC Spin	RHIC II	Future Upgrade
Emittance(95%) $\pi\mu m$	20	12	12
Beta function at IR [m]	1	1	0.3
Number of bunches	120	120	360
Bunch population [10^{11}]	2	2	2
Beam-beam parameter per IR	0.007	0.012	0.012
Angular size at IR [μrad]	112	86	157
RMS beam size at IR [μm]	112	86	47
Luminosity [10^{32} cm^{-2} s^{-1}]	2.4	4.0	40.0

RUN2001: Au-Au luminosity: 6×10^{26} cm^{-2} s^{-1} [N-N luminosity ~ 10^{31} cm^{-2} s^{-1}]

RHIC II : Beam-beam tune shift limited for 2 interaction regions

Future Upgrade: Mini-beta quads and more bunches

Will also require major detector upgrades

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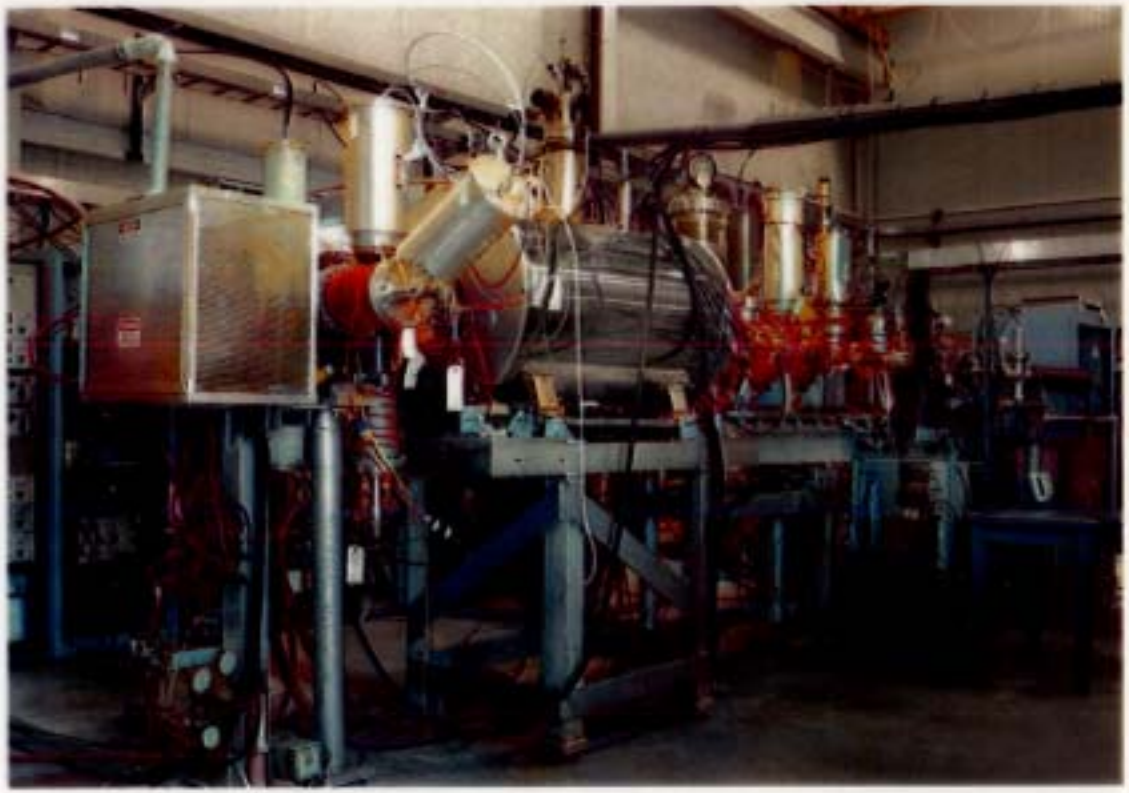
EBIS/Linac RHIC Pre-Injector

- Highly successful development of Electron Beam Ion Source (EBIS) at BNL
- Reliable, low maintenance Linac-based pre-injector replacing the Tandem Van de Graaffs
- EBIS allows for the production of high intensity uranium beams
- Ready to start construction



EBIS test stand

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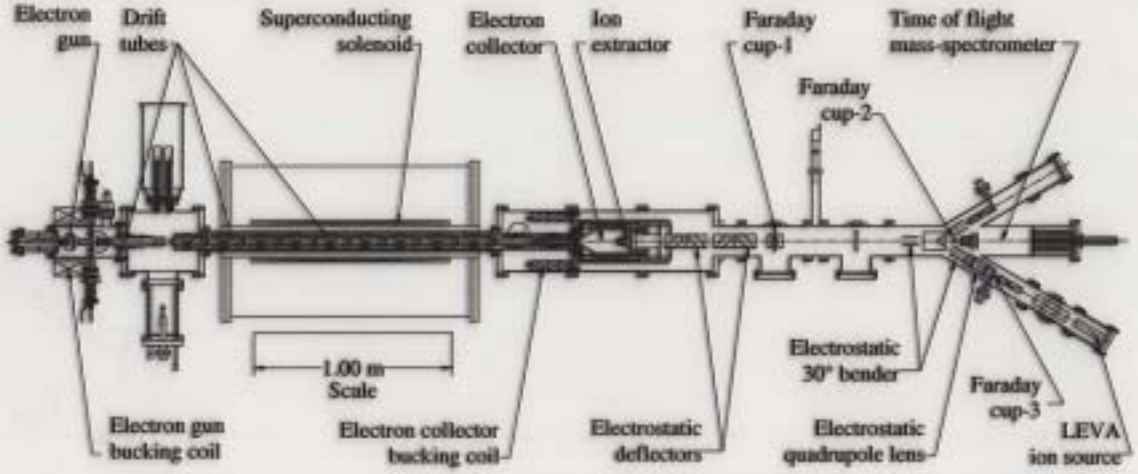
Results from Test EBIS (½ of RHIC EBIS)



	RHIC Requirements	Achieved
E-beam current	10 A	10 A
E-beam energy	20 keV	20 keV
Yield of pos. charges	5.5×10^{11} (Au, 10 A, 1.5m)	3.2×10^{11} (Au, 8 A, 0.7m)
Pulse length	≤ 40 μs	20 μs
Yield of Au^{33+}	3.4×10^{9}	~ 1.5×10^{9}
Yield of U^{45+}	2.4×10^{9}	

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Summary

- Full design Au luminosity achieved during RUN2001
- RHIC luminosity upgrades (RHIC II):
  - with existing machine: $\times 4$
  - with full energy electron cooler: $\times 10$ possible
- Further upgrades are possible:
  - Higher energy
  - Increased atomic number
  - Even higher luminosity with shorter bunches spacing and mini-beta interaction regions